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(54) **ON-CHIP RESONANCE DETECTION AND TRANSFER FUNCTION MAPPING OF RESISTIVE-INDUCTIVE-CAPACITIVE SENSORS**

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G01R 23/02 (2006.01)
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CPC ***G01R 35/005*** (2013.01); ***G01R 23/02*** (2013.01); ***G01R 27/02*** (2013.01); *G06F 3/0418* (2013.01)

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(Continued)

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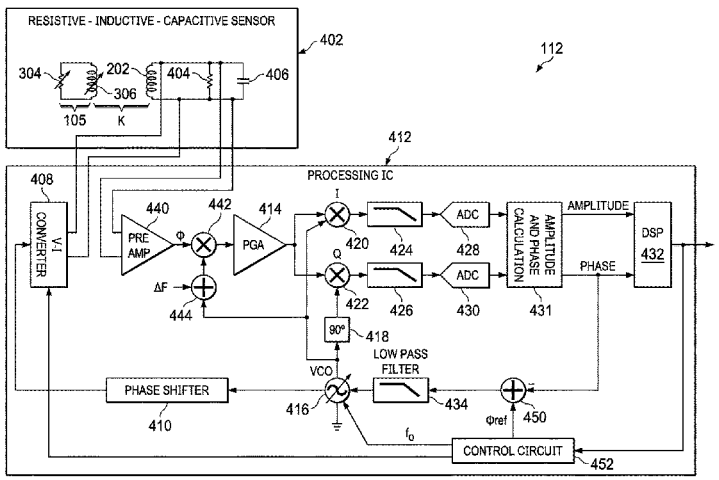
(57) **ABSTRACT**

A system may include a resistive-inductive-capacitive sensor, a driver configured to drive the resistive-inductive-capacitive sensor with a driving signal at a driving frequency, and a measurement circuit communicatively coupled to the resistive-inductive-capacitive sensor and configured to, during a calibration phase of the measurement circuit, measure phase and amplitude information associated with the resistive-inductive-capacitive sensor and based on the phase and amplitude information, determine at least one of a resonant frequency of the resistive-inductive-capacitive sensor and a transfer function of the resistive-inductive-capacitive sensor.

29 Claims, 4 Drawing Sheets



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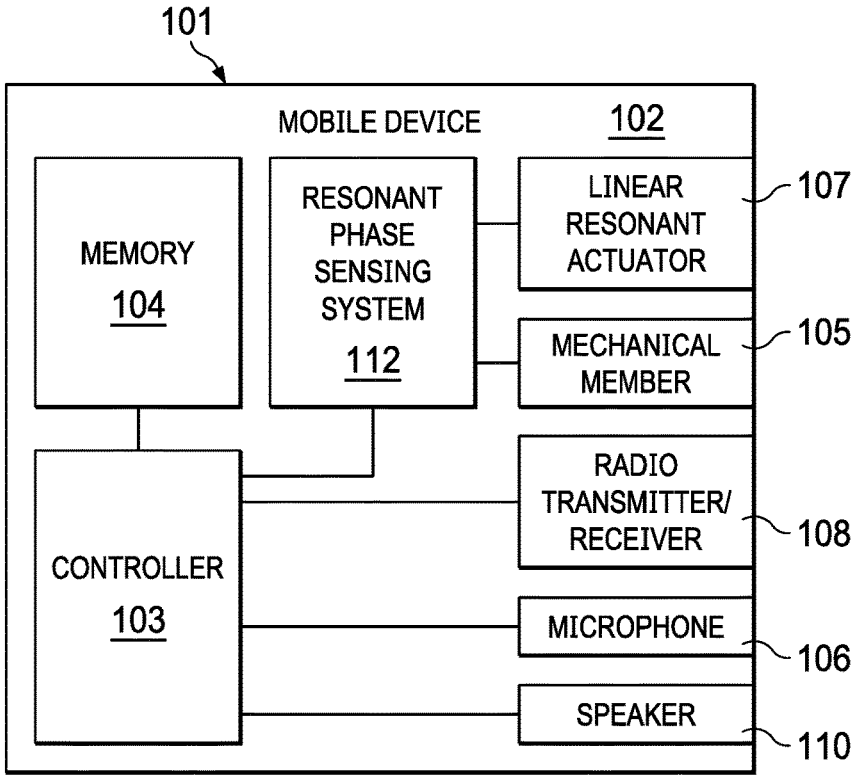

FIG. 1

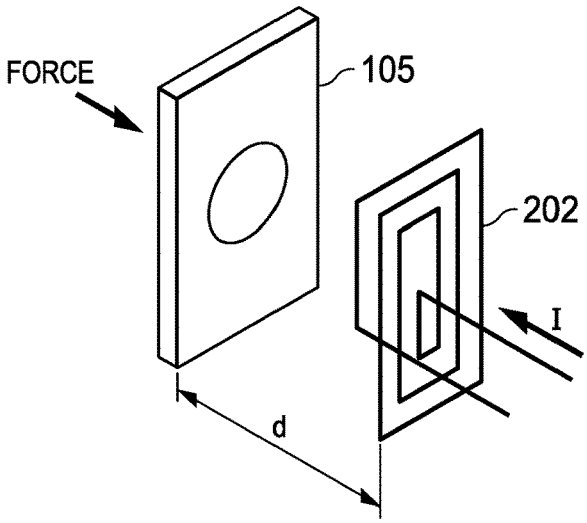

FIG. 2

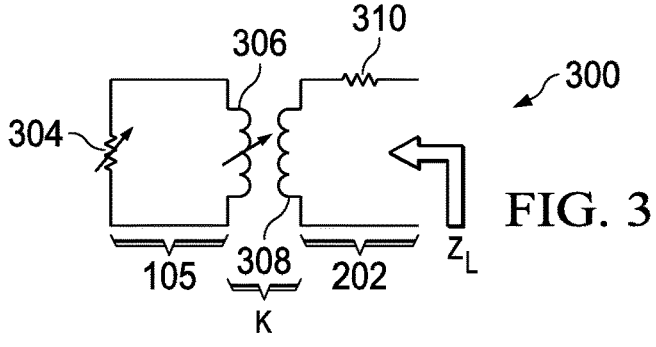

FIG. 3

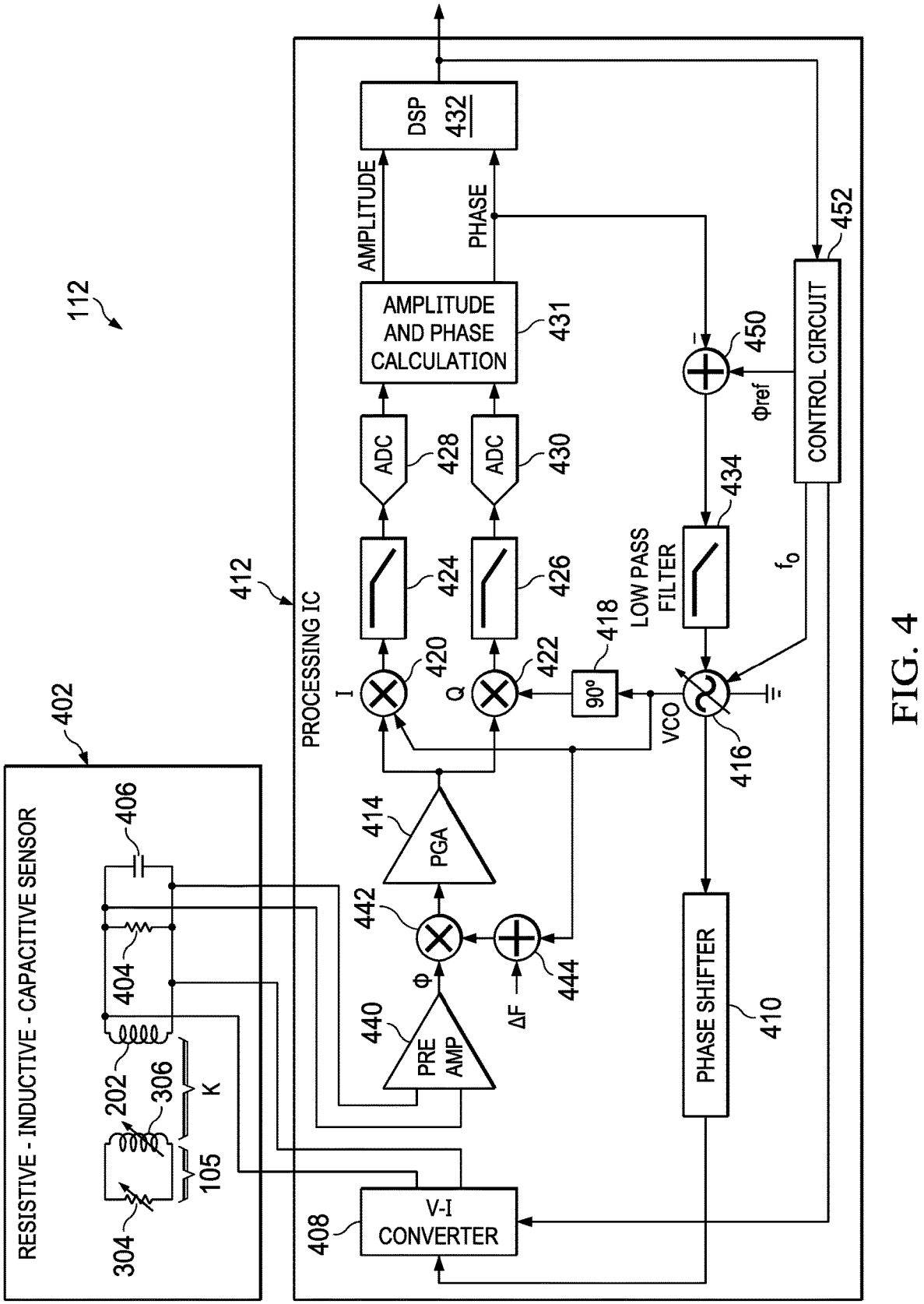
112
402
RESISTIVE - INDUCTIVE - CAPACITIVE SENSOR
406
404
202
306
K
105
304
412
PROCESSING IC
DSP 432
AMPLITUDE
PHASE
AMPLITUDE AND PHASE CALCULATION 431
ADC 428
ADC 430
424
426
I
Q
420
422
418
90°
LOW PASS FILTER
434
VCO
416
452
CONTROL CIRCUIT
450
Φref
f_o
414
PGA
442
Φ
ΔF
444
440
PRE AMP
PHASE SHIFTER 410
408
V-I CONVERTER

FIG. 4

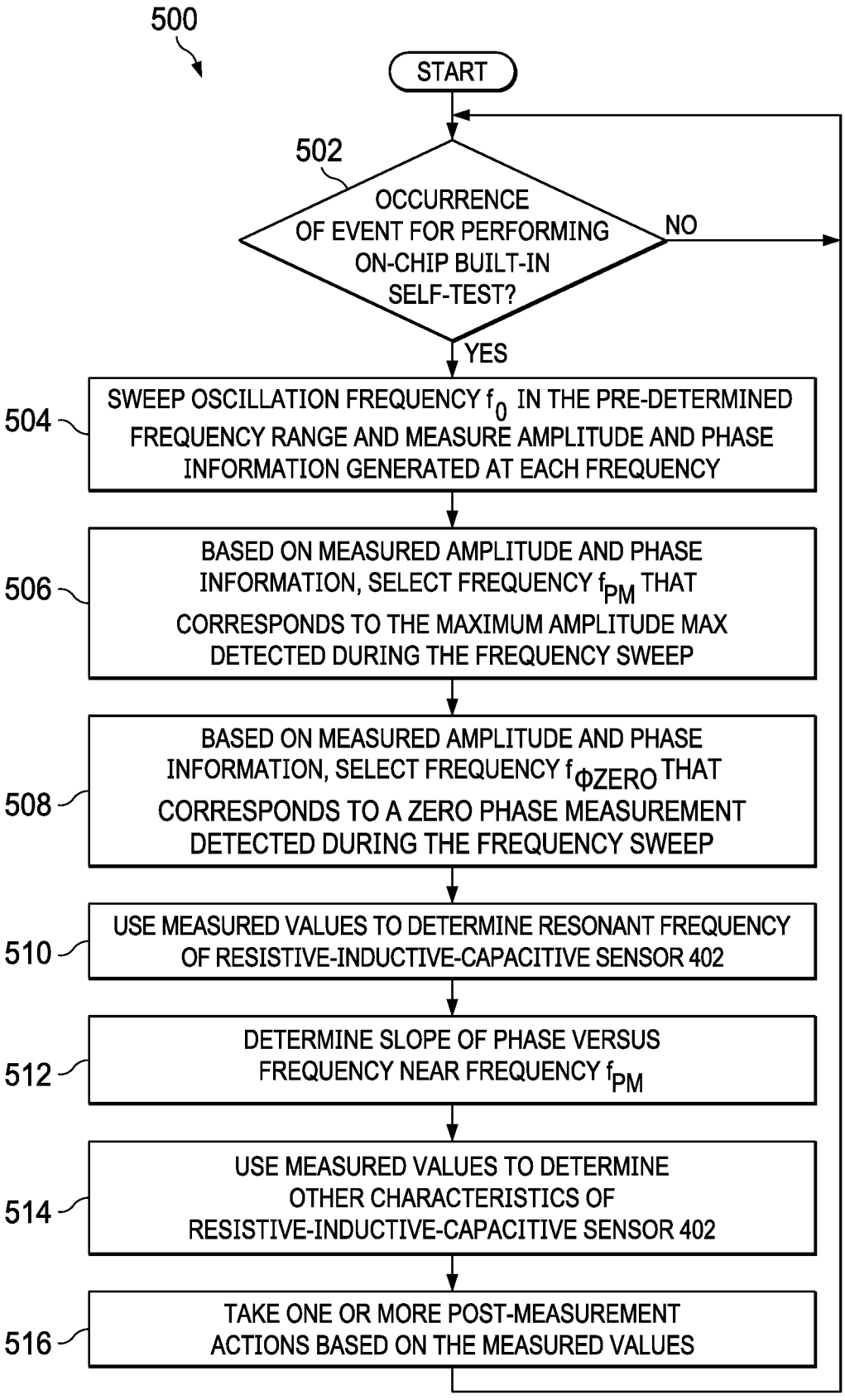
500
START
502
OCCURRENCE OF EVENT FOR PERFORMING ON-CHIP BUILT-IN SELF-TEST?
NO
YES
504
SWEEP OSCILLATION FREQUENCY f_0 IN THE PRE-DETERMINED FREQUENCY RANGE AND MEASURE AMPLITUDE AND PHASE INFORMATION GENERATED AT EACH FREQUENCY
506
BASED ON MEASURED AMPLITUDE AND PHASE INFORMATION, SELECT FREQUENCY f_{PM} THAT CORRESPONDS TO THE MAXIMUM AMPLITUDE MAX DETECTED DURING THE FREQUENCY SWEEP
508
BASED ON MEASURED AMPLITUDE AND PHASE INFORMATION, SELECT FREQUENCY $f_{\Phi ZERO}$ THAT CORRESPONDS TO A ZERO PHASE MEASUREMENT DETECTED DURING THE FREQUENCY SWEEP
510
USE MEASURED VALUES TO DETERMINE RESONANT FREQUENCY OF RESISTIVE-INDUCTIVE-CAPACITIVE SENSOR 402
512
DETERMINE SLOPE OF PHASE VERSUS FREQUENCY NEAR FREQUENCY f_{PM}
514
USE MEASURED VALUES TO DETERMINE OTHER CHARACTERISTICS OF RESISTIVE-INDUCTIVE-CAPACITIVE SENSOR 402
516
TAKE ONE OR MORE POST-MEASUREMENT ACTIONS BASED ON THE MEASURED VALUES

FIG. 5

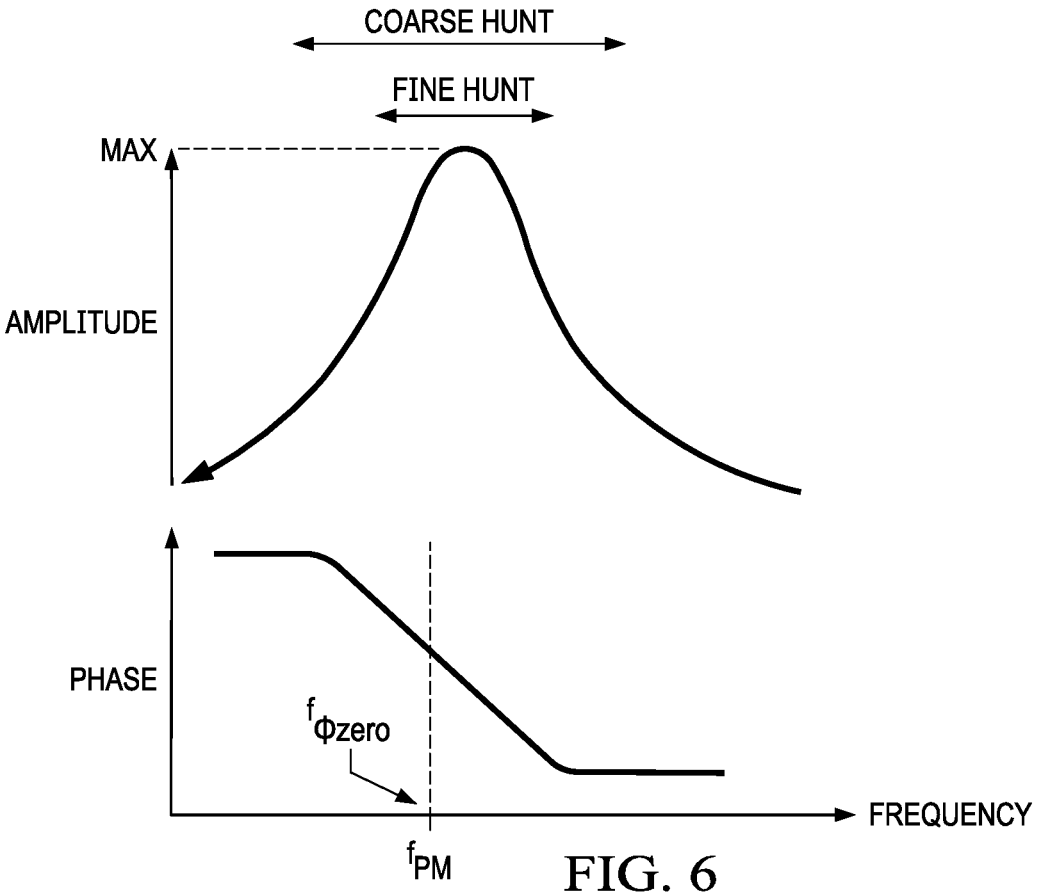
COARSE HUNT
FINE HUNT
MAX
AMPLITUDE
PHASE
$f_{\Phi zero}$
FREQUENCY
f_{PM}

FIG. 6

ON-CHIP RESONANCE DETECTION AND TRANSFER FUNCTION MAPPING OF RESISTIVE-INDUCTIVE-CAPACITIVE SENSORS

RELATED APPLICATIONS

The present disclosure claims priority to U.S. Provisional Patent Application Ser. No. 62/810,696, filed Feb. 26, 2019, which is incorporated by reference herein in its entirety.

The present disclosure relates to U.S. Provisional patent application Ser. No. 16/267,079, filed Feb. 4, 2019, U.S. Provisional Patent Application Ser. No. 62/649,857, filed Mar. 29, 2018, U.S. Provisional Patent Application Ser. No. 62/721,134, filed Aug. 22, 2018, and U.S. Provisional Patent Application Ser. No. 62/740,029, filed Oct. 2, 2018, all of which are incorporated by reference herein in their entireties.

FIELD OF DISCLOSURE

The present disclosure relates in general to electronic devices with user interfaces, (e.g., mobile devices, game controllers, instrument panels, etc.), and more particularly, resonant phase sensing of resistive-inductive-capacitive sensors for use in a system for mechanical button replacement in a mobile device, and/or other suitable applications.

BACKGROUND

Many traditional mobile devices (e.g., mobile phones, personal digital assistants, video game controllers, etc.) include mechanical buttons to allow for interaction between a user of a mobile device and the mobile device itself. However, such mechanical buttons are susceptible to aging, wear, and tear that may reduce the useful life of a mobile device and/or may require significant repair if malfunction occurs. Also, the presence of mechanical buttons may render it difficult to manufacture mobile devices that are waterproof. Accordingly, mobile device manufacturers are increasingly looking to equip mobile devices with virtual buttons that act as a human-machine interface allowing for interaction between a user of a mobile device and the mobile device itself. Similarly, mobile device manufacturers are increasingly looking to equip mobile devices with other virtual interface areas (e.g., a virtual slider, interface areas of a body of the mobile device other than a touch screen, etc.). Ideally, for best user experience, such virtual interface areas should look and feel to a user as if a mechanical button or other mechanical interface were present instead of a virtual button or virtual interface area.

Presently, linear resonant actuators (LRAs) and other vibrational actuators (e.g., rotational actuators, vibrating motors, etc.) are increasingly being used in mobile devices to generate vibrational feedback in response to user interaction with human-machine interfaces of such devices. Typically, a sensor (traditionally a force or pressure sensor) detects user interaction with the device (e.g., a finger press on a virtual button of the device) and in response thereto, the linear resonant actuator may vibrate to provide feedback to the user. For example, a linear resonant actuator may vibrate in response to user interaction with the human-machine interface to mimic to the user the feel of a mechanical button click.

However, there is a need in the industry for sensors to detect user interaction with a human-machine interface, wherein such sensors provide acceptable levels of sensor

sensitivity, power consumption, and size. One type of sensor that may be utilized to detect user interaction with a human-machine interface is a resistive-inductive-capacitive sensor. Characteristics (e.g., resonance frequency, transfer function) of a resistive-inductive-capacitive sensor may vary due to manufacturing variances, temperature drift, component aging, changes in mechanical structures, presence of electromagnetic interference, and/or other causes. Accordingly, to ensure accurate and precise measurement using a resistive-inductive-capacitive sensor, it may be desirable to measure and/or detect such characteristics for the purpose of calibration, quality factor determination, and/or noise reduction.

SUMMARY

In accordance with the teachings of the present disclosure, the disadvantages and problems associated with determining characteristics in a resistive-inductive-capacitive sensor may be reduced or eliminated.

In accordance with embodiments of the present disclosure, a system may include a resistive-inductive-capacitive sensor, a driver configured to drive the resistive-inductive-capacitive sensor with a driving signal at a driving frequency, and a measurement circuit communicatively coupled to the resistive-inductive-capacitive sensor and configured to, during a calibration phase of the measurement circuit, measure phase and amplitude information associated with the resistive-inductive-capacitive sensor and based on the phase and amplitude information, determine at least one of a resonant frequency of the resistive-inductive-capacitive sensor and a transfer function of the resistive-inductive-capacitive sensor.

In accordance with these and other embodiments of the present disclosure, a method may include during a calibration phase, measuring phase and amplitude information associated with a resistive-inductive-capacitive sensor driven by a driving signal at a driving frequency and during the calibration phase and based on the phase and amplitude information, determining at least one of a resonant frequency of the resistive-inductive-capacitive sensor and a transfer function of the resistive-inductive-capacitive sensor.

In accordance with embodiments of the present disclosure, a host device may include an enclosure and a resonant phase sensing system integral to the enclosure. The resonant phase sensing system may include a resistive-inductive-capacitive sensor, a driver configured to drive the resistive-inductive-capacitive sensor with a driving signal at a driving frequency, and a measurement circuit communicatively coupled to the resistive-inductive-capacitive sensor and configured to, during a calibration phase of the measurement circuit, measure phase and amplitude information associated with the resistive-inductive-capacitive sensor and based on the phase and amplitude information, determine at least one of a resonant frequency of the resistive-inductive-capacitive sensor and a transfer function of the resistive-inductive-capacitive sensor.

Technical advantages of the present disclosure may be readily apparent to one having ordinary skill in the art from the figures, description and claims included herein. The objects and advantages of the embodiments will be realized and achieved at least by the elements, features, and combinations particularly pointed out in the claims.

It is to be understood that both the foregoing general description and the following detailed description are

examples and explanatory and are not restrictive of the claims set forth in this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the present embodiments and advantages thereof may be acquired by referring to the following description taken in conjunction with the accompanying drawings, in which like reference numbers indicate like features, and wherein:

FIG. **1** illustrates a block diagram of selected components of an example mobile device, in accordance with embodiments of the present disclosure;

FIG. **2** illustrates a mechanical member separated by a distance from an inductive coil, in accordance with embodiments of the present disclosure;

FIG. **3** illustrates selected components of a model for a mechanical member and inductive coil that may be used in an inductive sensing system, in accordance with embodiments of the present disclosure;

FIG. **4** illustrates a diagram of selected components of an example resonant phase sensing system, in accordance with embodiments of the present disclosure;

FIG. **5** illustrates a flow chart of an example method for performing an on-chip built-in self-test of a resistive-inductive-capacitor sensor, in accordance with embodiments of the present disclosure; and

FIG. **6** illustrates an example graph depicting output amplitude and phase of a resistive-inductive-capacitive sensor obtained during an on-chip built-in self-test of the resistive-inductive-capacitor sensor, in accordance with embodiments of the present disclosure.

DETAILED DESCRIPTION

FIG. **1** illustrates a block diagram of selected components of an example mobile device **102**, in accordance with embodiments of the present disclosure. As shown in FIG. **1**, mobile device **102** may comprise an enclosure **101**, a controller **103**, a memory **104**, a mechanical member **105**, a microphone **106**, a linear resonant actuator **107**, a radio transmitter/receiver **108**, a speaker **110**, and a resonant phase sensing system **112**.

Enclosure **101** may comprise any suitable housing, casing, or other enclosure for housing the various components of mobile device **102**. Enclosure **101** may be constructed from plastic, metal, and/or any other suitable materials. In addition, enclosure **101** may be adapted (e.g., sized and shaped) such that mobile device **102** is readily transported on a person of a user of mobile device **102**. Accordingly, mobile device **102** may include but is not limited to a smart phone, a tablet computing device, a handheld computing device, a personal digital assistant, a notebook computer, a video game controller, or any other device that may be readily transported on a person of a user of mobile device **102**.

Controller **103** may be housed within enclosure **101** and may include any system, device, or apparatus configured to interpret and/or execute program instructions and/or process data, and may include, without limitation a microprocessor, microcontroller, digital signal processor (DSP), application specific integrated circuit (ASIC), or any other digital or analog circuitry configured to interpret and/or execute program instructions and/or process data. In some embodiments, controller **103** may interpret and/or execute program instructions and/or process data stored in memory **104** and/or other computer-readable media accessible to controller **103**.

Memory **104** may be housed within enclosure **101**, may be communicatively coupled to controller **103**, and may include any system, device, or apparatus configured to retain program instructions and/or data for a period of time (e.g., computer-readable media). Memory **104** may include random access memory (RAM), electrically erasable programmable read-only memory (EEPROM), a Personal Computer Memory Card International Association (PCMCIA) card, flash memory, magnetic storage, opto-magnetic storage, or any suitable selection and/or array of volatile or non-volatile memory that retains data after power to mobile device **102** is turned off.

Microphone **106** may be housed at least partially within enclosure **101**, may be communicatively coupled to controller **103**, and may comprise any system, device, or apparatus configured to convert sound incident at microphone **106** to an electrical signal that may be processed by controller **103**, wherein such sound is converted to an electrical signal using a diaphragm or membrane having an electrical capacitance that varies based on sonic vibrations received at the diaphragm or membrane. Microphone **106** may include an electrostatic microphone, a condenser microphone, an electret microphone, a microelectromechanical systems (MEMs) microphone, or any other suitable capacitive microphone.

Radio transmitter/receiver **108** may be housed within enclosure **101**, may be communicatively coupled to controller **103**, and may include any system, device, or apparatus configured to, with the aid of an antenna, generate and transmit radio-frequency signals as well as receive radio-frequency signals and convert the information carried by such received signals into a form usable by controller **103**. Radio transmitter/receiver **108** may be configured to transmit and/or receive various types of radio-frequency signals, including without limitation, cellular communications (e.g., 2G, 3G, 4G, LTE, etc.), short-range wireless communications (e.g., BLUETOOTH), commercial radio signals, television signals, satellite radio signals (e.g., GPS), Wireless Fidelity, etc.

A speaker **110** may be housed at least partially within enclosure **101** or may be external to enclosure **101**, may be communicatively coupled to controller **103**, and may comprise any system, device, or apparatus configured to produce sound in response to electrical audio signal input. In some embodiments, a speaker may comprise a dynamic loudspeaker, which employs a lightweight diaphragm mechanically coupled to a rigid frame via a flexible suspension that constrains a voice coil to move axially through a cylindrical magnetic gap. When an electrical signal is applied to the voice coil, a magnetic field is created by the electric current in the voice coil, making it a variable electromagnet. The voice coil and the driver's magnetic system interact, generating a mechanical force that causes the voice coil (and thus, the attached cone) to move back and forth, thereby reproducing sound under the control of the applied electrical signal coming from the amplifier.

Mechanical member **105** may be housed within or upon enclosure **101**, and may include any suitable system, device, or apparatus configured such that all or a portion of mechanical member **105** displaces in position responsive to a force, a pressure, or a touch applied upon or proximately to mechanical member **105**. In some embodiments, mechanical member **105** may be designed to appear as a mechanical button on the exterior of enclosure **101**.

Linear resonant actuator **107** may be housed within enclosure **101**, and may include any suitable system, device, or apparatus for producing an oscillating mechanical force across a single axis. For example, in some embodiments, linear resonant actuator **107** may rely on an alternating current voltage to drive a voice coil pressed against a moving mass connected to a spring. When the voice coil is driven at the resonant frequency of the spring, linear resonant actuator **107** may vibrate with a perceptible force. Thus, linear resonant actuator **107** may be useful in haptic applications within a specific frequency range. While, for the purposes of clarity and exposition, this disclosure is described in relation to the use of linear resonant actuator **107**, it is understood that any other type or types of vibrational actuators (e.g., eccentric rotating mass actuators) may be used in lieu of or in addition to linear resonant actuator **107**. In addition, it is also understood that actuators arranged to produce an oscillating mechanical force across multiple axes may be used in lieu of or in addition to linear resonant actuator **107**. As described elsewhere in this disclosure, a linear resonant actuator **107**, based on a signal received from resonant phase sensing system **112**, may render haptic feedback to a user of mobile device **102** for at least one of mechanical button replacement and capacitive sensor feedback.

Together, mechanical member **105** and linear resonant actuator **107** may form a human-interface device, such as a virtual interface (e.g., a virtual button), which, to a user of mobile device **102**, has a look and feel of a mechanical button or other mechanical interface of mobile device **102**.

Resonant phase sensing system **112** may be housed within enclosure **101**, may be communicatively coupled to mechanical member **105** and linear resonant actuator **107**, and may include any system, device, or apparatus configured to detect a displacement of mechanical member **105** indicative of a physical interaction (e.g., by a user of mobile device **102**) with the human-machine interface of mobile device **102** (e.g., a force applied by a human finger to a virtual interface of mobile device **102**). As described in greater detail below, resonant phase sensing system **112** may detect displacement of mechanical member **105** by performing resonant phase sensing of a resistive-inductive-capacitive sensor for which an impedance (e.g., inductance, capacitance, and/or resistance) of the resistive-inductive-capacitive sensor changes in response to displacement of mechanical member **105**. Thus, mechanical member **105** may comprise any suitable system, device, or apparatus which all or a portion thereof may displace, and such displacement may cause a change in an impedance of a resistive-inductive-capacitive sensor integral to resonant phase sense system **112**. Resonant phase sensing system **112** may also generate an electronic signal for driving linear resonant actuator **107** in response to a physical interaction associated with a human-machine interface associated with mechanical member **105**. Detail of an example resonant phase sensing system **112** in accordance with embodiments of the present disclosure is depicted in greater detail below.

Although specific example components are depicted above in FIG. **1** as being integral to mobile device **102** (e.g., controller **103**, memory **104**, mechanical member **105**, microphone **106**, radio transmitter/receiver **108**, speakers(s) **110**, linear resonant actuator **107**, etc.), a mobile device **102** in accordance with this disclosure may comprise one or more components not specifically enumerated above. For example, although FIG. **1** depicts certain user interface components, mobile device **102** may include one or more other user interface components in addition to those depicted in FIG. **1**, including but not limited to a keypad, a touch screen, and a display, thus allowing a user to interact with and/or otherwise manipulate mobile device **102** and its associated components. In addition, although FIG. **1** depicts only a single virtual button comprising mechanical member **105** and linear resonant actuator **107** for purposes of clarity and exposition, in some embodiments a mobile device **102** may have multiple virtual interfaces each comprising a respective mechanical member **105** and linear resonant actuator **107**.

Although, as stated above, resonant phase sensing system **112** may detect displacement of mechanical member **105** by performing resonant phase sensing of a resistive-inductive-capacitive sensor for which an impedance (e.g., inductance, capacitance, and/or resistance) of the resistive-inductive-capacitive sensor changes in response to displacement of mechanical member **105**, in some embodiments resonant phase sensing system **112** may primarily detect displacement of mechanical member **105** by using resonant phase sensing to determine a change in an inductance of a resistive-inductive-capacitive sensor. For example, FIGS. **2** and **3** illustrate selected components of an example inductive sensing application that may be implemented by resonant phase sensing system **112**, in accordance with embodiments of the present disclosure.

Although the foregoing contemplates a resonant phase sensing system **112** for use in a mobile device **102**, the resonant phase sensing system **112** may be used in any other suitable host device. A host device may include without limitation, a portable and/or battery-powered mobile computing device (e.g., a laptop, notebook, or tablet computer), a gaming console, a remote control device, a home automation controller, a domestic appliance (e.g., domestic temperature or lighting control system), a toy, a machine (e.g., a robot) such as a robot, an audio player, a video player, and a mobile telephone (e.g., a smartphone).

FIG. **2** illustrates mechanical member **105** embodied as a metal plate separated by a distance d from an inductive coil **202**, in accordance with embodiments of the present disclosure. FIG. **3** illustrates selected components of a model for mechanical member **105** and inductive coil **202** that may be used in an inductive sensing system **300**, in accordance with embodiments of the present disclosure. As shown in FIG. **3**, inductive sensing system **300** may include mechanical member **105**, modeled as a variable electrical resistance **304** and a variable electrical inductance **306**, and may include inductive coil **202** in physical proximity to mechanical member **105** such that inductive coil **202** has a mutual inductance with mechanical member **105** defined by a variable coupling coefficient k. As shown in FIG. **3**, inductive coil **202** may be modeled as a variable electrical inductance **308** and a variable electrical resistance **310**.

In operation, as a current I flows through inductive coil **202**, such current may induce a magnetic field which in turn may induce an eddy current inside mechanical member **105**. When a force is applied to and/or removed from mechanical member **105**, which alters distance d between mechanical member **105** and inductive coil **202**, the coupling coefficient k, variable electrical resistance **304**, and/or variable electrical inductance **306** may also change in response to the change in distance. These changes in the various electrical parameters may, in turn, modify an effective impedance Z_L of inductive coil **202**.

FIG. **4** illustrates a diagram of selected components of an example resonant phase sensing system **112**, in accordance with embodiments of the present disclosure. In some embodiments, resonant phase sensing system **112** may be

used to implement resonant phase sensing system **112** of FIG. **1**. As shown in FIG. **4**, resonant phase sensing system **112** may include a resistive-inductive-capacitive sensor **402** and a processing integrated circuit (IC) **412**.

As shown in FIG. **4**, resistive-inductive-capacitive sensor **402** may include mechanical member **105**, inductive coil **202**, a resistor **404**, and capacitor **406**, wherein mechanical member **105** and inductive coil **202** have a variable coupling coefficient k. Although shown in FIG. **4** to be arranged in parallel with one another, it is understood that inductive coil **202**, resistor **404**, and capacitor **406** may be arranged in any other suitable manner that allows resistive-inductive-capacitive sensor **402** to act as a resonant tank. For example, in some embodiments, inductive coil **202**, resistor **404**, and capacitor **406** may be arranged in series with one another. In some embodiments, resistor **404** may not be implemented with a stand-alone resistor, but may instead be implemented by a parasitic resistance of inductive coil **202**, a parasitic resistance of capacitor **406**, and/or any other suitable parasitic resistance.

Processing IC **412** may be communicatively coupled to resistive-inductive-capacitive sensor **402** and may comprise any suitable system, device, or apparatus configured to implement a measurement circuit to measure phase information associated with resistive-inductive-capacitive sensor **402** and based on the phase information, determine a displacement of mechanical member **105** relative to resistive-inductive-capacitive sensor **402**. Thus, processing IC **412** may be configured to determine an occurrence of a physical interaction (e.g., press or release of a virtual button) associated with a human-machine interface associated with mechanical member **105** based on the phase information.

As shown in FIG. **4**, processing IC **412** may include a phase shifter **410**, a voltage-to-current converter **408**, a preamplifier **440**, an intermediate frequency mixer **442**, a combiner **444**, a programmable gain amplifier (PGA) **414**, a voltage-controlled oscillator (VCO) **416**, a phase shifter **418**, an amplitude and phase calculation block **431**, a DSP **432**, a low-pass filter **434**, a combiner **450**, and a control circuit **452**. Processing IC **412** may also include a coherent incident/quadrature detector implemented with an incident channel comprising a mixer **420**, a low-pass filter **424**, and an analog-to-digital converter (ADC) **428**, and a quadrature channel comprising a mixer **422**, a low-pass filter **426**, and an ADC **430** such that processing IC **412** is configured to measure the phase information using the coherent incident/quadrature detector.

Phase shifter **410** may include any system, device, or apparatus configured to detect an oscillation signal generated by processing IC **412** (as explained in greater detail below) and phase shift such oscillation signal (e.g., by 45 degrees) such that a normal operating frequency of resonant phase sensing system **112**, an incident component of a sensor signal ϕ generated by pre-amplifier **440** is approximately equal to a quadrature component of sensor signal ϕ, so as to provide common mode noise rejection by a phase detector implemented by processing IC **412**, as described in greater detail below.

Voltage-to-current converter **408** may receive the phase shifted oscillation signal from phase shifter **410**, which may be a voltage signal, convert the voltage signal to a corresponding current signal, and drive the current signal on resistive-inductive-capacitive sensor **402** at a driving frequency with the phase-shifted oscillation signal in order to generate sensor signal ϕ which may be processed by processing IC **412**, as described in greater detail below. In some embodiments, a driving frequency of the phase-shifted oscillation signal may be selected based on a resonant frequency of resistive-inductive-capacitive sensor **402** (e.g., may be approximately equal to the resonant frequency of resistive-inductive-capacitive sensor **402**).

Preamplifier **440** may receive sensor signal ϕ and condition sensor signal ϕ for frequency mixing, with mixer **442**, to an intermediate frequency Δf combined by combiner **444** with an oscillation frequency f_0 generated by VCO **416**, as described in greater detail below, wherein intermediate frequency Δf is significantly less than the oscillation frequency. In some embodiments, preamplifier **440**, mixer **442**, and combiner **444** may not be present, in which case PGA **414** may receive sensor signal ϕ directly from resistive-inductive-capacitive sensor **402**. However, when present, preamplifier **440**, mixer **442**, and combiner **444** may allow for mixing sensor signal ϕ down to a lower intermediate frequency Δf which may allow for lower-bandwidth and more efficient ADCs (e.g., ADCs **428** and **430** of FIG. **4**) and/or which may allow for minimization of phase and/or gain mismatches in the incident and quadrature paths of the phase detector of processing IC **412**.

In operation, PGA **414** may further amplify sensor signal ϕ to condition sensor signal ϕ for processing by the coherent incident/quadrature detector. VCO **416** may generate an oscillation signal to be used as a basis for the signal driven by voltage-to-current converter **408**, as well as the oscillation signals used by mixers **420** and **422** to extract incident and quadrature components of amplified sensor signal ϕ. As shown in FIG. **4**, mixer **420** of the incident channel may use an unshifted version of the oscillation signal generated by VCO **416**, while mixer **422** of the quadrature channel may use a 90-degree shifted version of the oscillation signal phase shifted by phase shifter **418**. As mentioned above, oscillation frequency f_0 of the oscillation signal generated by VCO **416** may be selected based on a resonant frequency of resistive-inductive-capacitive sensor **402** (e.g., may be approximately equal to the resonant frequency of resistive-inductive-capacitive sensor **402**). Accordingly, as described in greater detail below, control circuit **452** may generate a control signal indicative of oscillation frequency f_0 and communicate such control signal to VCO **416** in order to cause VCO **416** to generate the oscillation signal at oscillation frequency f_0.

In the incident channel, mixer **420** may extract the incident component of amplified sensor signal ϕ, low-pass filter **424** may filter out the oscillation signal mixed with the amplified sensor signal ϕ to generate a direct current (DC) incident component, and ADC **428** may convert such DC incident component into an equivalent incident component digital signal for processing by amplitude and phase calculation block **431**. Similarly, in the quadrature channel, mixer **422** may extract the quadrature component of amplified sensor signal ϕ, low-pass filter **426** may filter out the phase-shifted oscillation signal mixed with the amplified sensor signal ϕ to generate a direct current (DC) quadrature component, and ADC **430** may convert such DC quadrature component into an equivalent quadrature component digital signal for processing by amplitude and phase calculation block **431**.

Amplitude and phase calculation block **431** may include any system, device, or apparatus configured to receive phase information comprising the incident component digital signal and the quadrature component digital signal and based thereon, extract amplitude and phase information.

DSP **432** may include any system, device, or apparatus configured to interpret and/or execute program instructions and/or process data. In particular, DSP **432** may receive the

phase information and the amplitude information generated by amplitude and phase calculation block **431** and based thereon, determine a displacement of mechanical member **105** relative to resistive-inductive-capacitive sensor **402**, which may be indicative of an occurrence of a physical interaction (e.g., press or release of a virtual button or other interaction with a virtual interface) associated with a human-machine interface associated with mechanical member **105** based on the phase information. DSP **432** may also generate an output signal indicative of the displacement. In some embodiments, such output signal may comprise a control signal for controlling mechanical vibration of linear resonant actuator **107** in response to the displacement.

Combiner **450** may subtract the phase information generated by amplitude and phase calculation block **431** from a reference phase ϕ_{ref} generated by control circuit **452** in order to generate an error signal that may be received by low-pass filter **434**. Low-pass filter **434** may low-pass filter the error signal, and such filtered error signal may be applied to VCO **416** to modify the frequency of the oscillation signal generated by VCO **416**, in order to drive sensor signal ϕ towards reference phase ϕ_{ref}. As a result, sensor signal ϕ may comprise a transient decaying signal in response to a "press" of a virtual button (or other interaction with a virtual interface) associated with resonant phase sensing system **112** as well as another transient decaying signal in response to a subsequent "release" of the virtual button (or other interaction with a virtual interface). Accordingly, low-pass filter **434** in connection with VCO **416** may implement a feedback control loop that may track changes in operating parameters of resonant phase sensing system **112** by modifying the driving frequency of VCO **416**.

Control circuit **452** may comprise any suitable system, device, or apparatus configured to generate a control signal indicative of reference phase ϕ_{ref} and a control signal indicative of oscillation frequency f_0. As described above, control circuit **452** may set oscillation frequency f_0 approximately equal to the resonant frequency of resistive-inductive-capacitive sensor **402**. Accordingly, control circuit **452** may be configured to determine the resonant frequency of resistive-inductive-capacitive sensor **402**, either during a calibration phase during end use of resistive-inductive-capacitive sensor **402** and/or during post-manufacturing testing and characterization of resistive-inductive-capacitive sensor **402** prior to intended end use. In addition, control circuit **452** may be configured to determine a transfer function of resistive-inductive-capacitive sensor **402**, as described in greater detail below.

Resonance detection of resistive-inductive-capacitive sensor **402** may be desired for a number of reasons, including without limitation a calibration during end-use operation of resistive-inductive-capacitive sensor **402** due to variance in characteristics of resistive-inductive-capacitive sensor **402** due to drift in operating temperature, changes due to component aging, changes in mechanical features of resistive-inductive-capacitive sensor **402** (e.g., air gaps, device bending, device twisting, device deformation, etc.), detection of errors, and/or presence of interfering noise (e.g., which may lead to modification of the resonant frequency of resistive-inductive-capacitive sensor **402**).

Transfer function mapping of resistive-inductive-capacitive sensor **402** may also be desired for a number of reasons, including without limitation that resistive-inductive-capacitive sensors may have wide manufacturing variances. Thus, performing a transfer function mapping of resistive-inductive-capacitive sensor **402** during post-manufacturing testing and characterization of resistive-inductive-capacitive sensor **402** prior to intended end use may aid in detecting sensor characteristics on a per sensor basis, detecting defects or faults in a sensor, and determining sensor characteristics in order to establish appropriate transmit and receive signal paths in processing circuitry. Performing transfer function mapping of resistive-inductive-capacitive sensor **402** during end use may aid in determining operational health of a sensor.

Resonance detection and transfer function mapping of resistive-inductive-capacitive sensor **402** may aid in determining an optimal resistive-inductive-capacitive sensor **402** and/or processing IC **412** operating point by measuring sensor phase, phase slope, amplitude, and/or quality factor in order to, for example, maximize measurement sensitivity of resistive-inductive-capacitive sensor **402**, as described in greater detail below.

FIG. **5** illustrates a flow chart of an example method **500** for performing an on-chip built-in self-test of resistive-inductive-capacitor sensor **402**, in accordance with embodiments of the present disclosure. According to some embodiments, method **500** may begin at step **502**. As noted above, teachings of the present disclosure may be implemented in a variety of configurations of mobile device **102**. As such, the preferred initialization point for method **500** and the order of the steps comprising method **500** may depend on the implementation chosen.

To further illustrate operation of method **500**, FIG. **6** illustrates an example graph depicting output amplitude and phase of resistive-inductive-capacitive sensor **402** obtained during an on-chip built-in self-test of resistive-inductive-capacitive sensor **402**, in accordance with embodiments of the present disclosure.

At step **502**, control circuit **452** may detect an occurrence of an event or a "trigger" for performing the on-chip built-in self-test of method **500**. An example of such an event may include an occurrence of an error (e.g., a phase measurement falling outside of expected bounds). Another example of such an event may include a periodic passage of time, such that the on-chip built-in self-test occurs at periodic intervals. An additional example of such an event may be the taking of a phase measurement, such that the on-chip built-in self-test is executed before each phase measurement. A further example is a measurement from another sensor of mobile device **102** falling outside a particular range (e.g., a temperature sensor, a motion sensor, and/or an optical sensor). Yet another example is a request from a host to perform the on-chip built-in self-test (e.g., a command from controller **103** of mobile device **102** and/or from a controller of a testing apparatus during testing and characterization of resonant phase sensing system **112** prior to its intended end use). Method **500** may remain at step **502** until such an event is detected. Once an event is detected, method **500** may proceed to step **504**.

At step **504**, control circuit **452** may sweep oscillation frequency f_0 in a predetermined frequency range and measure the amplitude and phase information generated by amplitude and phase calculation block **431** (e.g., as processed by DSP **432**) at each frequency. In some embodiments, control circuit **452** may also control voltage-to-current converter **408** to drive the driving signal to resistive-inductive-capacitive sensor **402** at a desired amplitude. In these and other embodiments, the measurements of step **504** may be performed in a coarse phase followed by a fine phase as shown in FIG. **6**: (i) in the coarse phase, control circuit **452** may sweep oscillation frequency f_0 across a wide frequency range (e.g., 2 Megahertz) and measure amplitude and phase information at some of the frequencies within the

range; and (ii) in the fine phase, near the frequency producing the largest amplitude during the coarse phase, control circuit **452** may sweep oscillation frequency f_0 across a narrower range but include all discrete possible discrete frequency levels within the narrower range. In these and other embodiments, the measurements of step **504** may be repeated multiple times and averaged before method **500** proceeds to step **506**, so as to reduce or eliminate the effects of noise on measurement.

At step **506**, control circuit **452** may, based on processed phase and amplitude information received from DSP **432**, select a frequency f_{PM} that corresponds to the maximum amplitude MAX detected during the frequency sweep of step **504** and store such frequency f_{PM} (e.g., in a memory integral to or otherwise accessible to control circuit **452**). In some embodiments, control circuit may also record phase ϕ_{PM} occurring at frequency that corresponds to the maximum amplitude detected during the frequency sweep of step **504** and store such phase ϕ_{PM} (e.g., in a memory integral to or otherwise accessible to control circuit **452**).

At step **508**, control circuit **452** may, based on processed phase and amplitude information received from DSP **432**, select a frequency $f_{\phi ZERO}$ that corresponds to a zero phase measurement detected during the frequency sweep of step **504** and store such frequency $f_{\phi ZERO}$ (e.g., in a memory integral to or otherwise accessible to control circuit **452**). In some implementations, determination of frequency $f_{\phi ZERO}$ may be performed with resistive-inductive-capacitive sensor **402** bypassed (e.g., resistive-inductive-capacitive sensor **402** decoupled from processing IC to determine frequency $f_{\phi ZERO}$ that corresponds to a zero phase measurement).

At step **510**, control circuit **452** may use frequency f_{PM}, phase ϕ_{PM}, and/or frequency $f_{\phi ZERO}$ to determine a resonant frequency of resistive-inductive-capacitive sensor **402**. At step **512**, control circuit **452** may determine a slope of phase versus frequency near frequency f_{PM} (e.g., based on two phase versus frequency measurements taken near frequency f_{PM}), and determine a quality factor for resistive-inductive-capacitive sensor **402** based on such phase slope.

At step **514**, control circuit **452** may use frequency f_{PM}, phase ϕ_{PM}, and/or frequency $f_{\phi ZERO}$ to determine other characteristics (e.g., other than resonant frequency and quality factor) of resistive-inductive-capacitive sensor **402**. For example, primary and secondary resonances of resistive-inductive-capacitive sensor **402** may be determined from a plot of amplitude versus frequency. As another example, an alternating current impedance versus frequency profile may be determined from frequency f_{PM}, phase ϕ_{PM}, and/or frequency $f_{\phi ZERO}$.

At step **516**, control circuit **452** may take one or more post-measurement actions based on the measurements of frequency f_{PM}, phase ϕ_{PM}, and/or frequency $f_{\phi ZERO}$. For example, control circuit **452** may recalibrate and generate oscillation frequency f_0 to the measured resonant frequency for resistive-inductive-capacitive sensor **402**, thus allowing for operation at maximum efficiency and sensitivity. As a result, VCO **416** and voltage-to-current converter **408** may adjust based on a recalibrated oscillation frequency f_0 to drive resistive-inductive-capacitive sensor **402** at or close to its resonant frequency.

As another example of a post-measurement action, control circuit **452** may declare an error and communicate an indication of such error if a measured quality factor, measured phase slope, and/or sensor transfer function parameters of resistive-inductive-capacitive sensor **402** falls outside of a predetermined acceptable range.

A further example is that, control circuit **452** may cause filtering on measured signals for amplitude and phase to occur such that noise is reduced or eliminated in measurements taken at or near secondary resonances.

As an additional example, if the resonant frequency of resistive-inductive-capacitive sensor **402** is determined to be at a frequency susceptible to noise, control circuit **452** may vary the resonant frequency of resistive-inductive-capacitive sensor **402** (e.g., by modifying capacitance **406** of resistive-inductive-capacitive sensor **402**).

After completion of step **516**, method **500** may proceed again to step **502**.

Although FIG. **5** discloses a particular number of steps to be taken with respect to method **500**, method **500** may be executed with greater or fewer steps than those depicted in FIG. **5**. In addition, although FIG. **5** discloses a certain order of steps to be taken with respect to method **500**, the steps comprising method **500** may be completed in any suitable order.

Method **500** may be implemented using control circuit **452** or any other system operable to implement method **500**. In certain embodiments, method **500** may be implemented partially or fully in software and/or firmware embodied in computer-readable media.

Using the method and systems disclosed herein, the measurements and transfer function mappings discussed herein are enabled as, instead of resistive-inductive-capacitive sensor **402** being part of a resonator or oscillator during the built-in self-test of control circuit **452**, resistive-inductive-capacitive sensor **402** is used as a passive load impedance actively driven by a driver. The built-in self-test varies frequency (and, in some embodiments, amplitude) of the drive irrespective of sensor resonance behavior, such that both amplitude and phase information associated with resistive-inductive-capacitive sensor **402** can be measured at multiple frequencies.

Although FIG. **4** represents one or more embodiments for implementing a resonant phase sensing system **112**, any other suitable resonant phase sensing system may be used consistent with this disclosure. For example, other example resonant phase sensing systems that may be used to implement resonant phase sensing system **112** are disclosed in U.S. patent application Ser. No. 16/267,079 filed Feb. 4, 2019 and entitled "Resonant Phase Sensing of Resistive-Inductive-Capacitive Sensors" and U.S. patent application Ser. No. 16/294,311 filed Mar. 6, 2019 and entitled "False Triggering Prevention in a Resonant Phase Sensing System," both of which are incorporated by reference herein in their entireties.

Although the foregoing contemplates use of closed-loop feedback for sensing of displacement, the various embodiments represented by FIG. **4** may be modified to implement an open-loop system for sensing of displacement. In such an open-loop system, a processing IC may include no feedback path from amplitude and phase calculation block **431** to VCO **416** or variable phase shifter **418** and thus may also lack a feedback low-pass filter **434**. Thus, a phase measurement may still be made by comparing a change in phase to a reference phase value, but the oscillation frequency driven by VCO **416** may not be modified, or the phase shifted by variable phase shifter **418** may not be shifted.

Although the foregoing contemplates use of a coherent incident/quadrature detector as a phase detector for determining phase information associated with resistive-inductive-capacitive sensor **402**, a resonant phase sensing system **112** may perform phase detection and/or otherwise determine phase information associated with resistive-inductive-

capacitive sensor **402** in any suitable manner, including, without limitation, using only one of the incident path or quadrature path to determine phase information.

In some embodiments, an incident/quadrature detector as disclosed herein may include one or more frequency translation stages that translate the sensor signal into direct-current signal directly or into an intermediate frequency signal and then into a direct-current signal. Any of such frequency translation stages may be implemented either digitally after an analog-to-digital converter stage or in analog before an analog-to-digital converter stage.

In addition, although the foregoing contemplates measuring changes in resistance and inductance in resistive-inductive-capacitive sensor **402** caused by displacement of mechanical member **105**, other embodiments may operate based on a principle that any change in impedance based on displacement of mechanical member **105** may be used to sense displacement. For example, in some embodiments, displacement of mechanical member **105** may cause a change in a capacitance of resistive-inductive-capacitive sensor **402**, such as if mechanical member **105** included a metal plate implementing one of the capacitive plates of capacitor **406**.

Although DSP **432** may be capable of processing phase information to make a binary determination of whether physical interaction associated with a human-machine interface associated with mechanical member **105** has occurred and/or ceased to occur, in some embodiments, DSP **432** may quantify a duration of a displacement of mechanical member **105** to more than one detection threshold, for example to detect different types of physical interactions (e.g., a short press of a virtual button versus a long press of the virtual button). In these and other embodiments, DSP **432** may quantify a magnitude of the displacement to more than one detection threshold, for example to detect different types of physical interactions (e.g., a light press of a virtual button versus a quick and hard press of the virtual button).

As used herein, when two or more elements are referred to as "coupled" to one another, such term indicates that such two or more elements are in electronic communication or mechanical communication, as applicable, whether connected indirectly or directly, with or without intervening elements.

This disclosure encompasses all changes, substitutions, variations, alterations, and modifications to the example embodiments herein that a person having ordinary skill in the art would comprehend. Similarly, where appropriate, the appended claims encompass all changes, substitutions, variations, alterations, and modifications to the example embodiments herein that a person having ordinary skill in the art would comprehend. Moreover, reference in the appended claims to an apparatus or system or a component of an apparatus or system being adapted to, arranged to, capable of, configured to, enabled to, operable to, or operative to perform a particular function encompasses that apparatus, system, or component, whether or not it or that particular function is activated, turned on, or unlocked, as long as that apparatus, system, or component is so adapted, arranged, capable, configured, enabled, operable, or operative. Accordingly, modifications, additions, or omissions may be made to the systems, apparatuses, and methods described herein without departing from the scope of the disclosure. For example, the components of the systems and apparatuses may be integrated or separated. Moreover, the operations of the systems and apparatuses disclosed herein may be performed by more, fewer, or other components and the methods described may include more, fewer, or other steps. Additionally, steps may be performed in any suitable order. As used in this document, "each" refers to each member of a set or each member of a subset of a set.

Although exemplary embodiments are illustrated in the figures and described below, the principles of the present disclosure may be implemented using any number of techniques, whether currently known or not. The present disclosure should in no way be limited to the exemplary implementations and techniques illustrated in the drawings and described above.

Unless otherwise specifically noted, articles depicted in the drawings are not necessarily drawn to scale.

All examples and conditional language recited herein are intended for pedagogical objects to aid the reader in understanding the disclosure and the concepts contributed by the inventor to furthering the art, and are construed as being without limitation to such specifically recited examples and conditions. Although embodiments of the present disclosure have been described in detail, it should be understood that various changes, substitutions, and alterations could be made hereto without departing from the spirit and scope of the disclosure.

Although specific advantages have been enumerated above, various embodiments may include some, none, or all of the enumerated advantages. Additionally, other technical advantages may become readily apparent to one of ordinary skill in the art after review of the foregoing figures and description.

To aid the Patent Office and any readers of any patent issued on this application in interpreting the claims appended hereto, applicants wish to note that they do not intend any of the appended claims or claim elements to invoke 35 U.S.C. § 112(f) unless the words "means for" or "step for" are explicitly used in the particular claim.

What is claimed is:

1. A system comprising:

a resistive-inductive-capacitive sensor;

a driver configured to drive the resistive-inductive-capacitive sensor with a driving signal at a driving frequency; and

a measurement circuit communicatively coupled to the resistive-inductive-capacitive sensor and configured to, during a calibration phase of the measurement circuit:

measure phase and amplitude information associated with the resistive-inductive-capacitive sensor; and

based on the phase and amplitude information, determine at least one of a resonant frequency of the resistive-inductive-capacitive sensor and a transfer function of the resistive-inductive-capacitive sensor.

2. The system of claim **1**, wherein the measurement circuit is further configured to, during the calibration phase, use at least one of the resonant frequency of the resistive-inductive-capacitive sensor and the transfer function of the resistive-inductive-capacitive sensor to monitor a health of the resistive-inductive-capacitive sensor.

3. The system of claim **1**, wherein the measurement circuit is further configured to, during the calibration phase, use at least one of the resonant frequency of the resistive-inductive-capacitive sensor and the transfer function of the resistive-inductive-capacitive sensor as a basis to modify one or more operational parameters of the system.

4. The system of claim **3**, wherein the one or more operational parameters comprises the driving frequency.

5. The system of claim **3**, wherein the one or more operational parameters comprises the resonant frequency.

6. The system of claim 1, wherein the measurement circuit is further configured to, during the calibration phase, determine at least one of the following from the phase and amplitude information:

a slope of phase versus frequency for the resistive-inductive-capacitive sensor;

a quality factor of the resistive-inductive-capacitive sensor;

a phase versus frequency profile for the resistive-inductive-capacitive sensor;

an amplitude versus frequency profile for the resistive-inductive-capacitive sensor;

primary and secondary resonances of the resistive-inductive-capacitive sensor;

maximum amplitude for the resistive-inductive-capacitive sensor and a frequency at which maximum amplitude occurs; and

an alternating impedance versus frequency profile for the resistive-inductive-capacitive sensor.

7. The system of claim 1, wherein the measurement circuit is further configured to, during the calibration phase, measure the phase and amplitude information at multiple frequencies of the driving signal.

8. The system of claim 7, wherein the measurement circuit is further configured to, during the calibration phase, measure the phase and amplitude information at multiple amplitudes of the driving signal.

9. The system of claim 1, wherein the measurement circuit is further configured to, during the calibration phase, measure the phase and amplitude information at multiple frequencies of the driving signal while bypassing the resistive-inductive-capacitive sensor from the measurement circuit.

10. The system of claim 1, wherein the measurement circuit is configured to initiate the calibration phase in response to an occurrence of an event for entering the calibration phase.

11. The system of claim 10, wherein the event comprises at least one of:

detection of an error associated with the resistive-inductive-capacitive sensor;

detection of a measurement of the resistive-inductive-capacitive sensor outside of expected bounds;

passage of a periodic duration;

measurement by the resistive-inductive-capacitive sensor to occur outside of the calibration phase;

measurement data of one or more sensors external to resistive-inductive-capacitive sensor being outside of respective expected bounds; and

a command to enter the calibration phase.

12. The system of claim 1, wherein the measurement circuit causes, in response to measurement of the phase and amplitude information, declaration of an error responsive to a quality factor, phase slope, or one or more parameters of the transfer function of the resistive-inductive-capacitive sensor being outside of respective expected bounds.

13. The system of claim 1, wherein the measurement circuit causes, in response to measurement of the phase and amplitude information, modification of one or more parameters of the system to reduce noise occurring at or near secondary resonances of the resistive-inductive-capacitive sensor.

14. The system of claim 1, wherein the measurement circuit is configured to, during a measurement phase of the measurement circuit:

measure phase information associated with the resistive-inductive-capacitive sensor; and

based on the phase information, determine displacement of a mechanical member relative to the resistive-inductive-capacitive sensor, wherein the displacement of the mechanical member causes a change in an impedance of the resistive-inductive-capacitive sensor.

15. A method comprising:

during a calibration phase, measuring phase and amplitude information associated with a resistive-inductive-capacitive sensor driven by a driving signal at a driving frequency; and

during the calibration phase and based on the phase and amplitude information, determining at least one of a resonant frequency of the resistive-inductive-capacitive sensor and a transfer function of the resistive-inductive-capacitive sensor.

16. The method of claim 15, further comprising, during the calibration phase, using at least one of the resonant frequency of the resistive-inductive-capacitive sensor and the transfer function of the resistive-inductive-capacitive sensor to monitor a health of the resistive-inductive-capacitive sensor.

17. The method of claim 15, further comprising, during the calibration phase, using at least one of the resonant frequency of the resistive-inductive-capacitive sensor and the transfer function of the resistive-inductive-capacitive sensor as a basis to modify one or more operational parameters of the system.

18. The method of claim 17, wherein the one or more operational parameters comprises the driving frequency.

19. The method of claim 17, wherein the one or more operational parameters comprises the resonant frequency.

20. The method of claim 15, further comprising, during the calibration phase, determining at least one of the following from the phase and amplitude information:

a slope of phase versus frequency for the resistive-inductive-capacitive sensor;

a quality factor of the resistive-inductive-capacitive sensor;

a phase versus frequency profile for the resistive-inductive-capacitive sensor;

an amplitude versus frequency profile for the resistive-inductive-capacitive sensor;

primary and secondary resonances of the resistive-inductive-capacitive sensor;

maximum amplitude for the resistive-inductive-capacitive sensor and a frequency at which maximum amplitude occurs; and

an alternating impedance versus frequency profile for the resistive-inductive-capacitive sensor.

21. The method of claim 15, further comprising, during the calibration phase, measuring the phase and amplitude information at multiple frequencies of the driving signal.

22. The method of claim 21, further comprising, during the calibration phase, measuring the phase and amplitude information at multiple amplitudes of the driving signal.

23. The method of claim 15, further comprising, during the calibration phase, measuring the phase and amplitude information at multiple frequencies of the driving signal while bypassing the resistive-inductive-capacitive sensor from the measurement circuit.

24. The method of claim 15, further comprising initiating the calibration phase in response to an occurrence of an event for entering the calibration phase.

25. The method of claim 24, wherein the event comprises at least one of:

detection of an error associated with the resistive-inductive-capacitive sensor;

detection of a measurement of the resistive-inductive-capacitive sensor outside of expected bounds;

passage of a periodic duration;

measurement by the resistive-inductive-capacitive sensor to occur outside of the calibration phase;

measurement data of one or more sensors external to resistive-inductive-capacitive sensor being outside of respective expected bounds; and

a command to enter the calibration phase.

26. The method of claim **15**, further comprising causing, in response to measurement of the phase and amplitude information, declaration of an error responsive to a quality factor, phase slope, or one or more parameters of the transfer function of the resistive-inductive-capacitive sensor being outside of respective expected bounds.

27. The method of claim **15**, further comprising causing, in response to measurement of the phase and amplitude information, modification of one or more parameters of the system to reduce noise occurring at or near secondary resonances of the resistive-inductive-capacitive sensor.

28. The method of claim **15**, further comprising, during a measurement phase of the measurement circuit:

measuring phase information associated with the resistive-inductive-capacitive sensor; and

based on the phase information, determining displacement of a mechanical member relative to the resistive-inductive-capacitive sensor, wherein the displacement of the mechanical member causes a change in an impedance of the resistive-inductive-capacitive sensor.

29. A host device comprising:

an enclosure; and

a resonant phase sensing system integral to the enclosure and comprising:

a resistive-inductive-capacitive sensor;

a driver configured to drive the resistive-inductive-capacitive sensor with a driving signal at a driving frequency; and

a measurement circuit communicatively coupled to the resistive-inductive-capacitive sensor and configured to, during a calibration phase of the measurement circuit:

measure phase and amplitude information associated with the resistive-inductive-capacitive sensor; and

based on the phase and amplitude information, determine at least one of a resonant frequency of the resistive-inductive-capacitive sensor and a transfer function of the resistive-inductive-capacitive sensor.

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